The Future of the Canadian Hydrocarbons Sector

Energy Technology Futures Workshop Final Draft Report
Delta Bow Valley Hotel, Calgary
March 30-31, 1999

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This workshop was sponsored by the Energy Technology Futures (ETF) project of Natural Resources Canada. It was part of the ETF initiative to identify technologies that could come into play in the period 2030 to 2050 and which could fundamentally alter the relationship between the growth of GHG emissions in Canada and the growth of the economy. Participants in the workshop were, to a large extent, from the western Canadian energy scene, and are listed in Annex 1.

The objective of the workshop was to examine the long-term (to the year 2050) technological opportunities for the extraction and processing of Canada's hydrocarbon resources, namely oil and natural gas, both conventional and unconventional, and coal on a sustainable basis, i.e. with reduced greenhouse gas (GHG) emissions. The specific objectives of the workshop were to:

- extend the thinking from the previous ETF Hydrocarbons Focus Group held on December 15, 1998, at the Alberta Department of Energy, Calgary (Annex 2)

- identify a more complete set of critical technologies, issues and gaps required for a sustainable hydrocarbons sector in the year 2050.

These objectives were examined by means of workshop break-out groups first of all to improve and augment the December 1998 "step-out" scenario, and secondly to develop key technologies for 2050 and their technological barriers in the three areas of clean oil, clean natural gas, and clean coal. In addition to examining specific technologies, break-out groups also identified potential Canadian strengths/niches and partners (both in Canada and internationally)

Utilization of these hydrocarbon sources, for example as fuels for transportation, was not included specifically within the terms of reference for the workshop because it is the subject of other discussions within the ETF project. However, inevitably the subject did arise in some of the debates, for example under coal. Because the emphasis of the workshop was on *sustainable* development within the Canadian hydrocarbons sector, the discussions under oil, natural gas, and coal, respectively, all included a component of technologies for CO_2 capture and disposal.

Key Conclusions and Observations

- In general, workshop participants agreed with the conclusion of the previous ETF Hydrocarbons Focus Group (December 15, 1998) that hydrocarbons used in a clean and sustainable manner will play an important role in Canada's economy in 2050.

- Development of supporting infrastructure, in particular for CO_2 capture, transport, and sequestration will be key for the hydrocarbon industry in 2050.

- No "silver bullets" to permit an easy path to hydrocarbon technology implementation were identified but the past parochial tendencies of federal/provincial R&D programs (and regulatory systems) must be avoided if Canada is to achieve its GHG goals; a properly-funded and coordinated national research effort is needed.

- The development of advanced materials was seen to be an issue of importance to all aspects of the hydrocarbons sector.

- Hydrocarbons-fuelled decentralized power generation may cause extra difficulties for CO_2 disposal.

- the following key technologies were identified for the sustainable use of oil to 2050: hydrogen technologies, biotechnology, underground (down-hole) processing, transmission technologies (a key issue), and closed-loop carbon production systems.

- The gas production sector, which will operate within a very integrated system, will access gas from a variety of sources ranging from conventional (including deep-well and sour) through frontier, synthetic, coal-bed methane, gas hydrates, and fugitive gas.

- Because of the long times for capital turnover, only two changes in routes to electricity from coal are possible in practical terms between now and 2050. CO_2 capture and sequestration will be increasingly practiced with today's technology, leading to a switch to integrated gasification combined-cycle electricity generation (IGCC) with complete CO_2 capture and sequestration at some intermediate date, ultimately leading to the co-production of electricity, hydrogen, and chemicals.

- Canada was seen to have some significant strengths upon which to build in the future both in terms of its natural resources (e.g. capacity for CO_2 sequestration in aquifers, coal seams, and in oil deposits) and its high-quality research capacity.

- The twin benefits of coal-bed methane technology (storing CO_2 and producing a fuel gas) should allow coal to be a positive contributor to sustainable hydrocarbons use in 2050, in contrast to the present views of coal's role in Canada's energy future.

Workshop Summary

In the introduction and workshop orientation session, Lindsey Patrick presented an overview of the Energy Technology Futures Project at Natural Resources Canada (NRCan). This overview (Annex 3) was brief because many of the workshop participants were familiar with the ETF process. In addition, the presentation is available on the ETF web site (www.nrcan.gc.ca/es/etf/). This project, which has as its goal to help Canada meet its climate change objectives and obligations whilst ensuring economic growth, is the only project that is looking beyond the Kyoto time frame. The ETF project is currently in the resource gathering stage, having convened in the order of ten workshops and focus groups since August, 1998. A virtual conference is also underway on the web site in which all workshop attendees were invited to

participate. Following this current round of workshops and focus groups, bilateral discussions on future technologies will take place with selected groups, e.g. at the Los Alamos National Laboratory, New Mexico. The next stages in the ETF process are to develop draft scenarios and then to conduct SWOT (strengths, weaknesses, opportunities, and threats) analyses.

Kevin Cliffe, Director of the ETF Project at NRCan noted that this initiative is one of a continuum. Other components include:

- Technologies for Early Action Measures (TEAM), which is designed to be a contributor to early initiatives for implementing GHG reduction technologies by offering additional support to federal programs that fund technology projects to reduce GHG emissions nationally and internationally, while sustaining economic and social development, and;

- the "Technology Issue Table" which is involved with medium-term strategy development to encourage technology innovation for mitigating GHG emissions.

The ETF initiative is expected to help both of the above measures.

In responding to a later question of "where does the process go from here", it was noted that the federal, provincial and territorial governments embarked upon a two-year process after Kyoto (in December, 1997) to develop an implementation plan to address the climate change issue from a national perspective. The ETF project hopes to develop recommendations on technology-related investment priorities in time to provide input into decisions on resource allocations for the year 2000 federal budget (these decisions are expected to take place in Fall, 1999).

Following these introductions to the workshop, presentations were made on the role of hydrocarbons in a sustainable energy sector in the year 2030 and beyond by:

- Daphne Cheel, Alberta Science and Research Authority (Annexes 4 and 5), and;

- Roger Bailey, Alberta Department of Energy (Annex 6).

Lindsey Patrick then reviewed briefly the results of the December, 1998, Hydrocarbons Focus Group (Annex 7) which was convened to develop a scenario for the Canadian hydrocarbons system in the period 2030-2050. The overall conclusion from that workshop was that hydrocarbons will remain a vital component of the Canadian economy. Workshop participants felt that we should not be embarrassed by our reliance on them, rather learn to use them in smarter and cleaner ways, and in a sustainable manner.

Break-Out Groups

Workshop participants then participated in three break-out groups, under the general headings of oil, natural gas, and coal, with the common assignment of improving and augmenting the December technology step-out scenario. Step-out technologies developed at the December workshop had been summarized on a single sheet under the headings of (i) electricity, (ii) oil

(conventional/non-conventional/heavy oil/oil sands), (iii) natural gas, (iv) coal, and (v) CO_2 capture and disposal.

Whilst the intent of the workshop was to focus on the role of technology in the sustainable development of Canada's hydrocarbon resources, inevitably issues arose relating to policy, regulations, programs, and funding. These concerns were not discarded but were recorded for future reference (Annex 8).

Following presentations of findings from these three break-out groups, the master sheet of step-out technologies was updated and circulated (see versions in Annex 9). Break-out groups then reconvened to address a second assignment. In this second round, key technologies for the year 2050, including attendant CO_2 capture and disposal technologies, were identified as well as the main technological barriers that need to be overcome and linkages that need to be addressed. Consideration was also given to partnerships and other forms of collaboration that would assist development of these technologies and where specific Canadian niches and strengths might exist.

Results from each of the second round of break-out groups were then presented and general conclusions from the workshop discussed.

Summary of Presentations to the Workshop

1. An Alberta Technology Strategy for the Management of Greenhouse Gas Emissions, Daphne Cheel, Alberta Science and Research Authority (Annexes 4 and 5)

The Alberta Technology Strategy for the Management of Greenhouse Gas Emissions, which has been a multi stakeholder process, is one element in the climate change strategy that the provincial government tabled in October, 1998. The strategy is designed to create an environment to ensure that technologies are available when needed, but not to choose any particular technology overall. A strength for Alberta is the Western Canada Sedimentary Basin, providing a sink for CO_2 after hydrocarbons extraction.

The strategic focus in the Strategy is on mitigation technologies, rather than on adaptation technologies, the strategic elements being technology intelligence, programs, and policy, and the stimulation of innovation through voluntary measures as well as through standards and regulatory measures. Ms. Cheel noted that Alberta knows how to use coal efficiently and cleanly and it represents a great export opportunity.
In order to make things happen, a collaborative virtual entity combining the three pillars of intelligence, policy, and R&D programs, is being put into place to bring together all of the players and to build upon current efforts. The three essential technologies to move the economy toward sustainability are information technology, biotechnology, and nanotechnology.

A quotation from Albert Einstein was particularly apropos to the current workshop:

> *"The world we created today as a result of our thinking thus far has problems which cannot be solved by thinking the way we thought when we created them".*

2. Energy Technology Futures, The Alberta Context 2030-2050, Roger Bailey, Alberta Department of Energy (Annex 6)

Roger Bailey underlined that he was expressing his personal opinions within the Alberta context of a federal workshop, noting that it is difficult to predict the effect of technological change in the future.

Currently, world primary energy use is hydrocarbon dominated, with oil and gas supplying about 50% of the requirements for transportation and primary heating. He predicted that this percentage would be about the same in 2050 but with changes in energy intensity in an increased world's population. Resources of conventional oil and gas may be insufficient to meet the needs but, depending on economics, tax regimes, etc., non-conventional sources will fill the gap. Even with the additional need for future CO_2 limitation, there may not be other alternatives to this hydrocarbons future. Attainment of post-Kyoto targets is a difficult challenge in such a future, needing technological as well as economic changes.

The issue with respect to gas is the price rather than extent of the resource, and coal-bed methane and methane hydrates could become sources within this time frame. The Athabasca Oil Sands (oil in place: 1.7 trillion barrels) are the resource of the future which will sustain us, although they are energy intensive to develop. The transportation costs of moving coal to markets have limited its utilization but ways have been developed to use it without CO_2 emissions. Vehicles are now available which use less than 5 litres/100km; it is instructive to note that putting 40 litres of fuel into a vehicle is the equivalent of transferring 20 MW of energy, which would require a thick cable if that energy were in the form of electricity. Opportunities exist for increasing the efficiency of the conversion of fuels to electricity, for example cogeneration. The contribution to the supply mix of electricity generated by wind may only be 10% in 2030+ and PV solar is limited. For comparison, New Mexico has four times the solar output of Alberta. (However, note that Alberta has about the same winter sun as the Gulf Coast of Texas because of cloud cover).

To meet 2030 CO_2 emission targets, incremental or step changes to technology will be insufficient, technologies that we do not yet know about being required.

In response to a question on the future role of nuclear energy, Mr. Bailey felt that it would not displace hydrocarbons. Even though there were no nuclear plants 50 years ago, the problems then were no more difficult than the problems surrounding CO_2 emissions today. Nuclear energy sets an upper price limit in that if the cost of fossil fuel electricity generation with CO_2 capture and sequestration cannot fall below this limit, nuclear will take over. However, it was pointed out that the decision in Alberta not to go nuclear had been a strictly political one.
It was also noted that fuel cell technology is developing very rapidly and that natural gas is predicted to be in short supply within a 50 year time horizon. A 10% wind energy penetration may be too high an estimate. With respect to fuel cells, it was noted that it is essential to compare technologies on a life-cycle basis.

Final Comments from Workshop Participants

- Because CO_2 removal will be essential in 2050, a system in which coal is actually a solver of the problem rather than being the culprit can be visualized, especially if hydrogen is used to heat homes with zero burner-tip emissions.

- Although the coal group had addressed the issue of trying to attain zero emissions, the natural gas and oil groups had not; the oil and gas industry needs to come to grips with the issue even though the problem may not be as extreme.

- "Diffuse" systems, such as the use of decentralized gas-fired small turbines, make the CO_2 problem worse, requiring a central disposal system or, alternatively, a hydrogen economy.

- Research funding should be directed toward coal bed methane and fuel cells in the shorter term.

- There have been several similar workshops over the past five years and the time has now come for action and an increased research effort.

- Discomfort was expressed with the concept of the research agenda being dominated by GHG issues; other issues which add economic value even though they might increase CO_2 emissions, should not be precluded.

- Significant research efforts are underway in other countries in some of the technology areas raised at this workshop, for example in ocean disposal in Japan and in aquifer sequestration in Norway. A cross-functional and integrated approach across diverse sectors, for example agricultural and medical, may open up new ideas.

- Information needs to be fed into a 'framework' to provide a more global approach to problem solving otherwise there is a danger that there will be a similar discussion five years hence.

- Information systems must be in place if money is to be spent on R&D.

Summary of Key Points from Assignment 1, Improving and Augmenting the December Step-out Scenario

(a) Oil Group (Clean Oil Technologies and CO_2 Sequestration)

In order to augment the step-out scenario developed in the December workshop, the Oil Group brainstormed over technologies that could emerge over the long-term in Canada to make hydrocarbon production sustainable with regards to greenhouse gas emissions, with an emphasis on upstream oil production and associated CO_2 capture and disposal technologies. The following general points emerged:

- Convergence of the fossil fuel industry (gas, oil, and coal) is occurring with regard to energy supply for electricity generation. Hybrid power generation industrial power systems may become prevalent, for example. Convergence of energy supply sources is also occurring on the consumer, and this has been driven by information technology (IT) and its capacity to coordinate. Other energy sources (e.g. petroleum coke, bitumen) need to be added to the step-out chart in order to identify alternative technologies. Identifying unconventional sources is also important.

- Smaller, economic plants are becoming available. There may be a future for micro-gas separation and micro-turbine technologies. Direct gas-fired electric generation technologies could break the 0.2MW techno-economic barrier (year 2010); they are also very beneficial in terms of CO_2 emissions.

- PV is near competitive in certain markets and will be penetrating retail markets by the year 2010. While PV will experience significant increases in market share, it will still remain a small contributor to electricity supply. It is worth drawing parallels with the telecom industry, with PV being the 'wireless' equivalent in the power industry.

- Biotechnology will play a key role in upgrading oil resources and assisting technological processes. For biomass systems, it could customize organisms for optimal energy production and help carve out niches for biofuels.

- Technical and economic issues need to be separated in forecasting technologies for 2050, as technologies are going to be successful depending on circumstances. A clear distinction should therefore be made between "invention", which considers technical and engineering possibilities, and "innovation", which situates invention in the economic and market framework. Evolution of technology can occur because of changes in technology ("invention") and/or changes in economics ("innovation").

- While most technology development will be incremental, the potential role of 'breakthrough' technologies must also be considered when looking at the year 2050 and beyond.

- The hydrogen economy will require efficient high-volume production technologies and storage capabilities.

- Distributed systems may in fact improve the reliability of power supply.
- Energy management will focus on integrated system design and exploit the potential of IT.
- Advancements in electricity transmission can have a high impact on the hydrocarbons industry, e.g. in-situ production of electricity in the Arctic and transmission by microwave.
- Social change or evolution, and/or innovation in instruments may help society deal with the emissions problem. One can take, as examples, concepts which were revolutionary in their day but are applied now in a standard fashion: income tax; Venetian double-entry accounting system.
- Carbon dioxide sequestration may be enhanced through oxygen-enriched combustion with membrane separation (ca. 2010). Alternatively, one can exploit biological fixation of CO_2 through forestry or agriculture or sequester CO_2 into natural hydrates. For offshore oil and gas production, 'closed-loop' CO_2 systems may be possible if the ocean can be used for sequestration and storage and if the incentive is there to do so (e.g. tax or emissions cap).
- Developing an economic use for CO_2, e.g. for chemicals and petrochemicals conversion, would greatly benefit sequestration efforts.

The Oil Group then specifically focussed its discussions on oil:

- Re-engineering of processes will be important over the next 50-year period. For instance, there is great potential for efficiency gains in oil production through capital stock turnover. The amount of steps required to take oil from an upstream to a downstream product could be significantly reduced, e.g. through field/on-site upgrading (near-term) or 'down-hole' processing of oil (far-term, ca. 2020). Integrated or 'systems approach' research is required as efforts have been traditionally separate.
- There will be greater automation, integration, and use of intelligent systems in oil production- "computers on every wellhead"- and for continuous emissions management. In fact, information gathering and control will be important for all industries, such as was the case in Japan's transformation of the car industry.
- The cost of CO_2-injection enhanced oil recovery (EOR) will be lowered when the disposal of CO_2 gains a value (i.e. when the Kyoto Protocol comes into effect).
- Improved solvent technology could replace SAGD (steam-assisted gravity drainage), including acid gas solvents if additional research can solve corrosion problems.
- Information technology (IT) could be used in exploration, for example to find deposits that are more amenable to CO_2-injection EOR.

- Improvements in horizontal drilling methods will make CO_2-EOR more economical.
- Technologies exist to reduce emissions from leakages, vents, etc. but currently there is no incentive to reduce emissions. It is also difficult to measure emissions and therefore precisely quantify reductions. The biggest problem is in venting.
- Energy efficiency measures, such as heat integration using cogeneration, could be applied at production facilities. Increased demand for and limited supply of oil will spur this development.
- Renewable and alternative energy technologies could be used, where economic, to supply electricity for oil & gas production facilities.
- Is there a potential use for nuclear energy in the enhanced recovery of oil?

(b) Natural Gas Group (Clean Natural Gas Technologies and CO_2 Sequestration)

In its discussions on key technologies needed for 2050 to ensure a sustainable hydrocarbon sector, the Natural Gas Group noted that technological advancement in Alberta has been mainly focused on oil, rather than gas. There is a need for companies to change from short-term thinking and target setting to long-term visioning. The Group arrived at the following conclusions and observations:

- the price structure for GHG's will determine the ability for Canada to meet the Kyoto target.
- "no urgency in this debate, industry and government have already given up on meeting targets set by Kyoto."
- North America may face larger shortages of natural gas than other developed countries
- the three main "wins" for Canada and Alberta are: coal bed methane, gas hydrates, and frontier exploration.
- representatives from the natural gas sector should participate in the next ETF workshop.

Although they were outside the scope of the Workshop, the Natural Gas Group identified a number of policy issues that bear on natural gas industry; these are listed below:

- the issue of a carbon tax regulation and when it may occur
- emissions trading – how can the natural gas industry capitalize on emissions trading?
- how does the work we are doing in Canada connect with the activities of other developed countries? Are they conflicting? Augmenting?

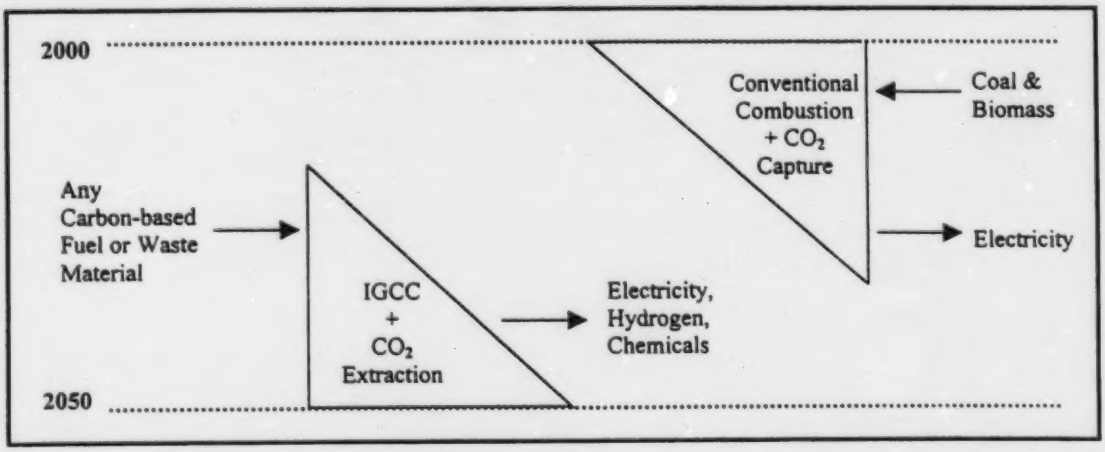
- need to be mindful of the "surprise/disruptive/unforeseen" technologies that may crop up
- lifestyle components need to be considered, e.g. personal choice of transportation
- life cycle analysis for technology assessments is necessary
- declining profitability of the Western Canada Sedimentary Basin reduces focus on R&D and local exploration
- federal/provincial relations and collaboration need to be improved.

(c) Coal Group (Clean Coal Technologies and CO_2 Sequestration)

The breakout group on coal first agreed upon an approach to the exercise, which included starting in the year 2050, and backcasting to the present (as opposed to forecasting from existing trends). In addition, in recognition of the scope of the workshop, the group agreed that they should take a national, rather than a regional or provincial, perspective. The group also chose to take a holistic biosphere approach to the issue, by examining those technologies that will enable the industry to do "really big things" in 2050.

The group then identified a number of trends or assumptions regarding the year 2050. They indicated that the entire hydrocarbon industry would be characterized by low CO_2 emissions by 2050, and that all energy sources would be used, although coal was expected to remain significant. In addition, they felt that technology development and transfer to developing countries would be key in the future. The group emphasized that 50 years is not a long time in terms of capital stock turnover (it represents at the most two turnover cycles), and that there is a real need to develop an infrastructure package, including carbon capture, transport, and sequestration. Some concerns were raised that a distributed electricity system may not be consistent with a sequestration economy.

The group then examined the technology step-out that had been produced at the December workshop. They agreed that, in general terms, the coal sector would see a transition over the next 50 years from the production of electricity from conventional coal power generation and CO_2 extraction, to IGCC (integrated gasification combined-cycle electricity generation) and CO_2 capture and sequestration with electricity, hydrogen and chemicals as key outputs. This evolution is described on the following page.



On the process side, the group also discussed a possible focus on the waste stream or development of a process to convert hydrocarbon fuel to carbon-free energy.

A number of policy issues were also identified that will affect the future of the hydrocarbon industry in Canada. These include the impact of deregulation in the electricity sector, the key role played by the market place, the need for financial incentives, shifts in global demographics, Canada's place in the North American context, and timing of potential government action.

Summaries of Assignment 2, Key Technologies for 2050 and the Technological Barriers

For this assignment, participants in each of the three groups were asked to imagine being R&D managers for a "Canadian Clean Hydrocarbons Technologies Lab" and to decide which actions need to be taken now and in the future to develop the new, sustainable hydrocarbon energy technologies. Economic and policy constraints were to be ignored.

(a) Oil Group (Clean Oil Technologies and CO_2 Sequestration)

Participants in the Oil Group agreed that some kind of prioritization was needed to be imposed in their minds to enable the team to agree on those R&D areas that could offer the greatest potential for enabling CO_2 reductions and benefits for the industry. The following R&D areas, or 'drivers', were chosen, *but not ranked*:

- Hydrogen technologies
- Biotechnology
- Underground processing
- Transmission technologies
- Closed-loop carbon production systems
- Information technology (IT)

Hydrogen Technologies:

Hydrogen was deemed to be important because of how it could leverage the hydrocarbon industry. The addition of hydrogen into the carbon chain would benefit the upgrading of oil through an increased H_2:C ratio. Currently, there are two steps (or pathways) for the integration of hydrogen into the hydrocarbon industry:

(i) Producing H_2

Methods available are:

- Electrolysis
- Steam-methane (or other hydrocarbon) reforming Cracking with H_2S (constraint because sources are limited) or CH_4
- Use of catalysts What is needed is a method to produce cheap H_2, or to do it 'down-hole'.

(ii) Addition of H_2 into the carbon chain

It would be useful to look at processes where more than one by-product is valuable. A breakthrough technology would allow the elimination of step (i) above, and to add water or CH_4 directly into the hydrocarbon (heavy oil or bitumen).

Biotechnology:

Biotechnology was not discussed specifically by the Oil Group, but was mentioned in relation to both extraction (see "underground processing", below) and upgrading processes.

Underground Processing:

Significant environmental and other benefits could accrue from moving the entire processing/upgrading step 'down-hole' and being left with a high quality hydrocarbon product to extract. However, the extremely hostile (acidic) environment involved would cause difficulties. The following is a set of technologies that would have to be developed to allow the down-hole processing of oil:

- Advanced processes (including biological) for in-situ upgrading (e.g. to separate oil from water), using catalysts, process additives, and/or solvents
- Advanced materials (anti-corrosive materials and perhaps 'smart' materials which could vary properties according to conditions) and materials handling capabilities
- Advanced instrumentation, control methods (e.g. expert systems) and components (e.g. valves) for optimal extraction under changing conditions
- Telemetry (e.g. use of virtual reality) and advanced robotics.

Underground processing can be seen as an extension of the horizontal drilling concept. Control and monitoring would be required to follow the 'pay zone' and gain the side benefit of extending the life of the deposit.

Transmission Technologies:

Initially, the concept of advanced transmission using microwave power systems was suggested as a way to eliminate CO_2 leakage in pipeline transmission (corresponding to 2% of all emissions in Canada), while possibly increasing efficiency of transmission. Since a significant side benefit would be the exploitation of remote deposits which now have prohibitive transportation costs, it was agreed that a broad range of possible 'transport of energy' technologies would be considered. It was recognized beforehand, however, that the development of transport technologies would benefit gas more than oil because the pipeline transport of gas is much less efficient than that for oil.

The following potential energy transport technologies were put forward by the group for consideration:

Oil/gas ⇨ electricity ⇨ microwave ⇨ electricity ⇨ power/energy

Work would likely be required to improve the efficiency and/or reduce costs of each conversion step along the chain. Improving electricity/microwave conversion would be key, as would selecting the optimal microwave transmission system (e.g. via towers or satellite reflection). There is the possibility of eliminating steps, such as using a chemical conversion process to turn gas directly into microwave power (e.g. MASER- Microwave Amplifying Stimulated Emission Radiation). At the other end of the chain, one could use microwave-voltaics to convert microwaves directly into electricity, e.g. low-power microwaves being converted to electricity through panels integrated into buildings.

Gas ⇨ liquid ⇨ pipeline (liquid) or tanks

The gas to liquid conversion step is expected to be solved before 2050. However, transport by airship and gas container ('blimp') to avoid the gas to liquid conversion step could be envisioned.

For pipeline transmission, advanced technologies and techniques could improve efficiencies, e.g. advanced materials, improved valves, multiple pumps, multiphase flow monitoring, and expert systems for control. Perhaps there is a role for a 'capsule' pipeline system (i.e. like the old-fashioned pressure tube system to transport money/instructions for businesses). Also, cheaper or alternative construction methods (e.g. automatic construction of pipelines) could enable further extension of pipelines into remote areas and over difficult terrain.

For tank transport (from the Arctic), advanced hull designs would be required to meet climatic conditions. Amphibious or submarine vessels could be envisioned to transport liquids.

High Pressure Gas Pipelines

The aim would be to develop gas pipelines which can handle a three-fold increase in pressure. Again, advanced materials, improved valves, multiple pumps, multiphase flow monitoring, and expert systems for control are important as in liquid pipeline transmission. For gas systems,

better leak detection and correction methods could be found (e.g. infrared monitoring with robotic repair). LNG pipeline systems require insulating materials as well as cheaper cryogenic processes.

Hybrid Systems *(e.g. methane or H_2)*
Smilar challenges and opportunities as described above.

Gas Solid
Gas would be converted directly into a solid, through hydrates, to intensify the energy content per unit volume. Solid transport could then be used, e.g. 'gas-bergs' to move gas out of remote or Arctic regions.

Closed-Loop Carbon Production Systems:

The goal in closed-loop carbon production systems would be to achieve zero net CO_2 emissions in oil production, not including emissions from consumption. Norway, for example, is pumping offshore CO_2 into North Sea aquifers. Also, CO_2 is being injected into coal beds. In an ideal situation, oil would be "creamed" off and all undesirable effluents, not just CO_2, would be returned or recycled back 'down-hole', e.g. re-injection of acid gas.

A solution for flaring emissions would be to use the gas as energy input for electricity production. However, several obstacles still remain:

- regulators are needed for the grid to accept produced electricity
- smaller micro-turbines (now at 0.5 MW) are required
- power generators that work effectively on raw gas need to be developed
- emissions monitoring technologies are required
- micro-separation technologies for emissions control need to be developed.

Another solution to flaring would be to be use of a catalytic oxidation process to eliminate flaring completely (convert CH_4 to CO_2). It would also reduce electricity consumption because power is required to drive compressors for flaring. This potential solution could also be applied to vent gas.

Information Technology:

Information technology was not dealt specifically by the Oil Group as it was considered a crosscutting technology and would be considered in other R&D thrusts. However, the Group was of the view that IT will be an important component of technology development over the next 50 years.

Priority Assumptions:

The Oil Group felt that in order to successfully tackle the above (or any other) research and development areas, the following 'priority assumptions' will need to be taken

on-board by governments:

- coordination of national research (it is currently piecemeal)
- coordination of research internationally ("don't re-invent the wheel")
- proper level of capital and staff funding for research
- funding of 'curiosity'/breakthrough research
- establishment of private/public partnerships

Final thoughts pertinent to the workshop from the Oil Group were as follows:

- transport will be a key issue for the hydrocarbon sector in the future
- coal will continue to play a significant role
- down-hole processing is the most innovative concept
- basic research is imperative; Canada can compete in turning basic research into applications.

(b) Natural Gas Group (Clean Natural Gas Technologies and CO_2 Sequestration)

Assignment Two conclusions from the Natural Gas Group are summarized in Tables 1 and 2, below:

Table 1: Identification of Barriers/Gaps, Key Canadian Partners, and Canadian Niche/Strength in the Natural Gas Industry

BARRIERS/GAPS	KEY PARTNERSHIPS/ COLLABORATIONS	CANADIAN NICHE/STRENGTHS
• Difficulty making gas transportation system greenhouse gas neutral (length, isolation) • No incentive to drill to deep saline reservoirs • Greenhouse gas neutral gas wells and gathering systems (fugitive gas, pumping, compression). Also a technology development need. • Upstream/midstream/ • downstream R&D • communications • disconnect (particularly • around marginal • sources)	• For East and West Coast offshore: with UK, Norway, Denmark, Greenland • For gas hydrates and coal bed methane: R&D consortium with Western Europe, Japan, U.S. • For basic research: Government and private sector combined • For basin specific development: Company consortia • For pipeline and compressor technology: International consortia	• Sour gas (H_2S) • H_2 production from sour gas (Canada should take R&D lead) • Arctic gas production (Canada should take R&D lead) • Deep well acid gas injection and disposal (Canada as lead) • Sedimentary basin disposal • Pipeline construction • Favours collaborative environment (R&D) • Largest and most secure source of natural gas in North America • Gas hydrates R&D • Canada is one of the largest countries with large potential quantities of sinks and sequestration

Table 2: Outlook to the years 2000-2050 on Technology Developments and Other/Enabling Technologies Needed for the Natural Gas Industry

Year	Technology Development	Other Enabling Technologies
2000	• Alternate operation means for gas well sites and gathering systems (roughly 10 MT CO_2) • Biotechnology R&D separation technology for marginal sources (important for local niche supplies, moral and societal reasons) • GHG capture and re-injection field management (for CO_2 capture and sequestration)	• Gas separation technologies • H_2 production from sour gas wells • Separation and capture technology • Economic feasibility studies for: - H_2S/CO_2 - N_2 - H_2O - Gas liquid
2010	• Isolated compressor stations – GHG neutral (17 MT CO_2) including oil	
2020	• Coal bed methane - production and reservoir management technology • gas hydrates - production and management technology • Frontier gas production management technology	
2030		
2040		• Others to develop gasifier technology and coal, biomass and animal waste
2050	• CO_2 neutral production and transport • Energy transmission technology	

(c) Coal Group (Clean Coal Technologies and CO_2 Sequestration)

The Coal Group group approached Assignment #2 by first identifying key priority technologies, and then brainstorming on potential barriers, niches and partners in the development and penetration of these technologies. The group examined both technologies with near-term potential (or that are ongoing now), as well as longer term development goals to the year 2050 which may or may not represent immediate priorities.

Four priority areas were identified by the group:

- gasification
- CO_2 capture
- transport, and
- sequestration.

Of these, CO_2 capture, transport and sequestration were considered the top priority, with gasification representing a secondary concern. Within the sequestration package, CO_2 transport was not addressed in detail, although technological barriers were identified (see below).

For each priority area, the group brainstormed on a list of potential technological barriers, given below.

CO_2 Capture:

- * scrubbing
- CO_2/oxygen combustion
- * direct CO_2 extraction from air (dilute stream CO_2)
- bioengineering/enhanced CO_2 capture
- membranes for CO_2 capture

CO_2 Transport:

- pipeline technology
- materials
- short term storage
- chemical/heat compressors
- sea-based tanker technology

CO2 Sequestration:

- * aquifers
- depleted oil/gas fields
- mineralization
- ocean disposal
- enhanced oil recovery
- * coal bed methane
- biomass

Gasification:

- low-cost air separation
- gas clean up technologies
- * solid oxide fuel cells
- advanced gas turbines
- * anaerobic gasification
- methane cracking
- advanced materials

The top two barriers for each area, indicated with a star above, were then selected for further study. The development of advanced materials was considered to be a cross-cutting requirement for virtually all technologies identified.

Each of these priority areas is discussed in greater detail below, with the exception of 'CO_2 Transport', considered to be the lowest priority area. The group examined each technology by addressing the question as to how many R&D dollars should be spent in each area, including areas in which further work could be commissioned. Spending priorities were meant to reflect a long term view, rather than short term economic investment priorities. The group also identified potential Canadian strengths, as well as potential partners, for each technology explored.

CO_2 Capture:

a) *Scrubbing*

Barriers:

- advanced amines
- advanced packing (mass transfer)
- alternatives to amines
- energy use reduction
- materials for construction (corrosion)
- hydrates ⇨ CO_2/H_2O hydrates

Canadian Strengths:

- scrubbing technologies (Alberta sour gas plants)
- process design and operation
- University of Saskatchewan
- hydrates
- University of Calgary (natural gas/CO2 hydrates)

Potential Partners:

- University of Saskatchewan (scrubbing)
- University of Calgary (hydrates)
- US Department of Energy
- Norway

b) *Direct CO_2 extraction from air*

(Note: this technology has the advantage of being measurable, but is specific to distributed sources only.)

Barriers:

- concept development
- treatment of large input volumes
- chemical acceptors which enable rapid capture of CO_2
- mass ocean storage

Canadian Strengths:

- huge geographic area
- University of Victoria (chemical absorbents of CO_2)

Partners:

- United Technologies (space air clean up)
- US Department of Energy

CO2 Sequestration:

a) *Aquifers*

Barriers:

- field testing (large scale)
- lab studies (chemistry)
- outstanding compression/injection issues
- corrosion and completion design
- environmental impact

Canadian Strengths:

- hydrogeology
- Canadian acid gas injection into wells
- Alberta Geological Survey/Alberta Research Council

Partners:

- Norway (working test in progress)
- Shell (South China Sea)
- US DOE – Los Alamos

b) *Coal Bed Methane (CBM)*
(Note: CBM has significant sequestration potential, and could enable zero emission energy production.)

Barriers:

- reservoir dynamics
  - underground coal seam characteristics
  - water behaviour
- injectant quality (detailed work)
- absorption/desorption process
- potential sterilization of coal seams
- properties of high rank coals
- completion and system design

Canadian Strengths:

- gas infrastructure
- drilling and completion technology
- Norwest Mining Consultants (experience in coal-bed methane drainage)
- Alberta Research Council

Partners:

- Burlington Resources (U.S.)
- AMOCO
- U.K. Atomic Energy Authority, Harwell
- Dutch government

Gasification:

a) *Solid Oxide Fuel Cells*

Barriers:

- size
- life
- materials development
- use as a gasifier (in combustor of the gas turbine)
- economics and integration into gas turbines
- operation in dirty, hot environments

Canadian Strengths:

- OHT (Ontario Hydro Technologies) – developing a pressurized SOFC
- Alberta – Global Thermalelectric

Partners:

- Westinghouse/Siemens
- US Department of Energy

b) *Anaerobic Gasification*

For example:

$CaO + 2H_2O + C \Rightarrow CaCO_3 + 2H_2$

$CaCO_3 \Rightarrow CaO + CO_2$

(the energy requirements for above reactions are almost balanced)

Barriers:

- pilot plant to produce CO_2 stream
- gas clean up, which could be an alternative to a hydrogen separation membrane

Canadian Strengths:

- raw materials

Partners:

- US Department of Energy
- Louisiana State University

Annexes

1. Workshop Participants
2. Summary Report of the ETF Hydrocarbon Focus Group, December 15, 1998, Alberta Department of Energy, Calgary, Alberta
3. Energy Technology Futures Project at Natural Resources Canada (NRCan)
4. An Alberta Technology Strategy for the Management of Greenhouse Gas Emissions by Daphne Cheel, Alberta Science and Research Authority
5. Identifying Critical Technologies - A First Step. (distributed by Daphne Cheel)
6. Energy Technology Futures, The Alberta Context 2030-2050, Roger Bailey, Alberta Department of Energy
7. Results from Hydrocarbon Focus Group of December 15, 1998
8. Policy Issues arising from Assignment 1
9. Revised Technology Step-Out Sheets

ANNEX 1

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ETF Hydrocarbon Workshop
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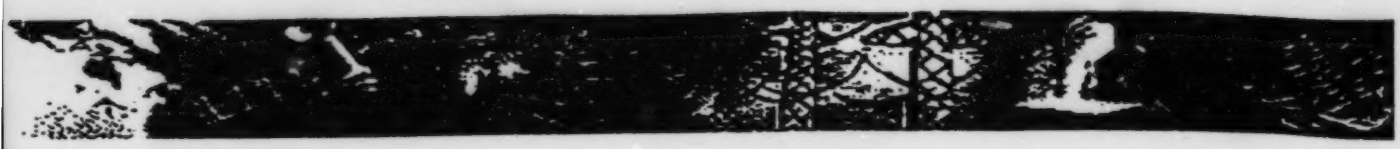
ANNEX 2

Summary Report of the ETF Hydrocarbon Focus Group
December 15, 1998, Alberta Department of Energy, Calgary, Alberta



SUMMARY REPORT OF THE ETF HYDROCARBON FOCUS GROUP

December 15, 1998,
Alberta Department of Energy,
Calgary Alberta

PURPOSE

The charge to the group was to develop long term scenarios (2050) for a sustainable hydrocarbon energy system. Each participant was asked to envision:

- What the hydrocarbon economy could look like in 2050?
- What technologies, including CO_2 capture and disposal would be required to make the hydrocarbon industry greenhouse gas (GHG) neutral?
- How and over what timeframe could these technologies evolve?

HYDROCARBON CONDITIONS IN 2050

By the year 2050, the state of the industry could be very similar to that of today.

- Canada could continue to be a world producer of hydrocarbons,
- energy consumption patterns will not likely change dramatically, and
- Canadians will continue to demand and use our existing "liquid fuels" infrastructure.

Sources of supply of Canadian hydrocarbons could become more remote, and somewhat more energy intensive. Oil from conventional wells currently non-producing could become viable given the growing use of CO_2 injection (the value of CO_2 disposal in wells could make these sources more economic than they are currently). In addition, the energy production and distribution systems could be collapsed and merged for greater efficiency.

The significant investment in fuel cells could start to pay off in their application in distributed power systems. Coal could continue to play a major role in the energy system particularly in the use of CO_2 storage for the production of coal-bed methane, or through the gasification of coal to liquid fuels (including electrochemical separation).

Natural gas could remain an important source either in direct applications or through the production of syngas. Natural gas, while cleaner than other hydrocarbon fuels, should have a premium, and its use should match this higher value; i.e., natural gas should not be used as a bridging fuel or in point sources (electricity production). In additional non-producing natural gas wells could be used for CO_2 storage over the longer term.

The Green Society is a more centralised urban society that relies greatly on advanced communications (e.g. tele-commuting, tele-medicine) and a mass public transportation system. It relies on localised solutions and personal choice is important. Industry tends to be light and distributed.

The Consuming Society is characterised by continued urban sprawl. Society continues to value personal mobility, but demands highly efficient vehicles. Society demands the cleanest, cheapest and most reliable energy source. Individuals look to industry and government for centralised solutions. Economic growth is emphasised. Industry tends to be large scale and integrated, with a greater emphasis on energy utilisation (i.e., co-generation, networked and by-product synergies).

CONCLUSION

It was agreed that such discussions regarding the future of role of hydrocarbons in a sustainable energy economy are essential. Hydrocarbons are an important part of the Canadian economy and as such our wealth and dependence on them should not embarrass us. Rather, Canada should learn to use then smarter and cleaner – in a sustainable manner. Given our vast knowledge, Canada could strive to develop and adopt clean hydrocarbon technologies.

ATTENDEES:

Allan Amey, Technologies and Assessment, TransCanada Pipelines
Roger Bailey, Director, Research and Technology Branch, Alberta Department of Energy
Graham Boje, Shell Canada
Amit Chakma, Dean, Faculty of Engineering, University of Regina
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Malcolm Wilson, Resources Policy and Economics Division, Saskatchewan Energy and Mines
Dr. C.S. Wong, Climate Chemistry Laboratory, Fisheries and Oceans Canada
Paul W. Young, Environmental Programs, Petro-Canada

Attachment

Fossils

- Acid gas solvents for HO/OS production
- Bioprocessing of HO/OS
- Biodesigned fuels
- Super fuels
- Hydrogen Diesel

Natural Gas

- CBM
- NG decarbonisation
- Syngas from coal, residues, and gasification
- Underground coal gasification
- Gas hydrates as a source of NG
- In situ gas disassociation

ANNEX 3

Energy Technology Futures Project at Natural Resources Canada (NRCan)

ENERGY TECHNOLOGY FUTURES

The Conceptual Framework

- ETF is a scenario planning project
- Intent of ETF is to move beyond current frame & focus to:
  - develop a set of visions of Canada's energy system in 2030 to 2050
  - develop options for technologies and fuels to meet Canada's energy needs with reduced GHG intensity

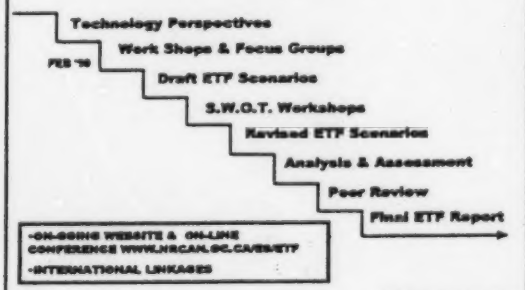
Scope & Coverage

- Areas of energy service demands & their characteristics
- Technologies to meet these needs & characteristics
- Energy sources, fuels, carriers
  - on-grid and off-grid
- Cross cutting technologies impacting on GHG & energy needs

Main Inputs

- Workshops
  - Cross-cutting technologies
  - Electricity, Hydrocarbons planned
- Focus Groups
  - seven areas covered
- Bilateral discussions
  - domestic & International
- Peer review
- Web Site www.nrcan.gc.ca/es/etf

ETF Process



Objectives of the Workshop

- Build on the results of the December workshop by improving the technology step-out chart
- Brainstorm on potential visions of the nature and structure of the Canadian hydrocarbon system in 2050.
- Identify key technologies ,R&D technology issues, gaps, and critical technologies.

ANNEX 4

An Alberta Technology Strategy for the Management of Greenhouse Gas Emissions

by Daphne Cheel, Alberta Science and Research Authority

An Alberta Technology Strategy for the Management of Greenhouse Gas Emissions

Energy Technology Futures' Workshop
March 30, 1999

Daphne Cheel
Alberta Science and Research Authority

Vision

- Through the innovative use and creation of knowledge and technology, Alberta's economic well-being will be enhanced while lowering the province's net production of greenhouse gases.

Objectives

- To ensure the effective deployment of greenhouse gas mitigation technologies within Alberta
- To capitalize on the global opportunities for GHG-friendly products and technology solutions for the economic benefit of Alberta

by creating an environment that ensures that identified critical technologies are available when required.

Creating the Environment . . .

- Changing and broadening the technology focus
- Identifying critical technologies
- Allowing technology selection through market forces
- Stimulating innovation
- Coupling technology change with production growth
- Taking advantage of export opportunities
- Communicating technology successes
- Identifying and eliminating barriers
- Creating Opportunities for Synergy

Strategic Focus

- Green-house Gas Mitigation Technologies
  - Reducing energy intensity or the quantity of energy used per unit of output (increasing efficiency)
  - Reducing carbon intensity in energy production and utilization
  - Capturing, sequestering, using, or storing greenhouse gas emissions (especially feasible for carbon dioxide)
  - Using other specific mitigation strategies for greenhouse gases other than carbon dioxide

Strategic Elements

- Technology Intelligence
  - connecting to the world technology pool
- Technology Programs
  - R&D to catalyze technology application in Alberta
- Technology Policy
  - identifying and recommending solutions to technology barriers

Alberta Centre
for Climate Change
Technology

The world we created today as a result of our thinking thus far has problems which cannot be solved by thinking the way we thought when we created them.

Albert Einstein

- Global climate change is about sustainable development
- Achieving sustainability requires the whole system to change

There is a huge opportunity for re-invention

The Challenge

- Think about what's happening in the world . . .
  Look at areas of stress in natural systems . . .
  Imagine how your company / university / business could meet human needs with new products that don't aggravate - that perhaps even repair - ecological stresses.

ANNEX 5

Identifying Critical Technologies - A First Step
(distributed by Daphne Cheel)

Identifying critical technologies – a first step . . .

Technology Focus Areas		GHG Reduction Potential (Mt CO_2E)	Tech. Role	Alberta R&D Capability	Export Opp.	Relative Priority
Fossil Fuel Supply	Hydrocarbon Recovery Methods	> 10	Developer	High	Yes	High
	Energy Efficiency in Fossil Fuel Production	5 to 10	Developer	Moderate	Yes	Moderate
	Fugitive Emissions Recovery and Use	5 to 10	Developer	Moderate	Yes	Moderate

Identifying critical technologies – a first step . . .

Technology Focus Areas		GHG Reduction Potential (Mt CO_2E)	Tech. Role	Alberta R&D Capability	Export Opp.	Relative Priority
Non-Energy Related	Agricultural CH4 Management	< 5	Developer	High	Yes	Moderate
	Agricultural N2O Management	< 5	Developer	High	Yes	Moderate
	Landfill Gas Recovery and Use	< 5	User	Low	No	Low

Identifying critical technologies – a first step . . .

Technology Focus Areas		GHG Reduction Potential (Mt CO_2E)	Tech. Role	Alberta R&D Capability	Export Opp.	Relative Priority
CO2 Management	Geological Storage	> 10	Developer	High	Yes	High
	Agricultural Sequestration	< 5	Developer	High	Yes	Moderate
	Forest Sequestration	< 5	Developer	High	Yes	Moderate
	CO2 Capture	> 10	Adapter	Moderate	Yes	High
	CO2 Infrastructure and Transportation	Indirect	Adapter	Low	No	Low

ANNEX 6

Energy Technology Futures, The Alberta Context 2030-2050

Roger Bailey, Alberta Department of Energy

Energy Technology Futures
The Alberta Context 2030-2050

- Oil and Gas >50% primary energy
  - transportation (gasoline,diesel)
  - residential heating (gas)
  - process heat and power (co-generation) (gas)
  - electrical (co-generation, IGCC (coal, gas)
  - hydrogen from hydrocarbons
- Alternatives increased (solar, PV, wood)
- Renewables increased (hydro, wind)

World Primary Energy Use 1996

Alberta Context 2030
Hydrocarbon Production Province

- Are the resources sustainable? Yes but...
  - Gas: conventional? deep, CBM, hydrates?
  - Oil: conventional? CO2 EOR, Oil Sands
- Are they economic? Yes but...
  - World commodity price rules
  - Cost will be are greater
- Are there alternatives? Not really!
- Are CO2 emissions OK? Not really!

Alberta Context 2030 Gas

- Are the gas resources available?
  - premium fuel for limiting CO2
  - h/c ratio, co-gen efficiencies etc
  - Conventional reserves depleted
  - Tight deep gas, Coal bed Methane expensive
  - Hydrates? Offshore and permafrost

Alberta Context 2030 Oil

- Are the oil resources available?
  - Conventional oil depleted
  - EOR with CO2 in place
  - Oil Sands largest oil resource in the world
    - Mining potential 250 billion barrels
    - SAGD Potential 240 billion Barrels
    - Non thermal solvent processes will be developed

Alberta Context 2030+ Coal

- Are the resources available? Coal
- Coal is Alberta's largest hydrocarbon resource
- Use has been limited by transportation costs
- CO2 emissions will limit coal use
- IGCC with CO2 Recovery is the answer
  - Integrated gasification Combined Cycle
  - Oxygen gasification with Water Gas Shift
  - Hydrogen/Air turbine with heat recovery

Are There Alternatives? Transportation Fuels

- Efficient vehicles available < 5 l/100 k
- Liquids preferred: energy density, range and charge rate (20 MW)
- Low pollution gasoline and diesel fuels available
- Hydrogen Fuel cell, electric cars? Niches only
- Bio-Alcohol? No! Bad production yields and energy efficiencies (100 kg of wood yields 20 kg or 30 liters of fuel)

Are There Alternatives? Electricity Production

- Demand side management? Yes
  - efficiency and conservation
  - New standards and techniques in place by 2030
- Wind ? Good CO2 benefits but capacity limited to 10 to 20 %
- PV Solar? Niche applications
- Gas? Distributed cogeneration common but $
- Coal? IGCC with WGS and CO2 capture

Alberta Context 2030+ Are CO2 Emissions OK?

- Voluntary Challenges met, efficiency improved , energy intensity reduced
- JI Offsets applied, net emissions reduced
- Capital stock turned over
- CO2 used for EOR and CBM
- CO2 sequestered in reservoirs and aquifers
- Emissions are still above target, and increasing!

Cellulosic Ethanol

- 100 kg wood yields ~60 kg cellulose
- Costs well known from pulp production
- Cellulose is carbohydrate Cn(H2O)n
- Fuel value is the carbo not the hydrate
- One third of the carbon is emitted in the fermentation as CO2
- The product is ~ 10% solution with a fuel equivalent of 20 kg or 30 liters of gasoline
- The wastes can fuel the processes

ANNEX 7

Results from Hydrocarbon Focus Group of December 15, 1998

ENERGY TECHNOLOGY FUTURES

Results of Hydrocarbon Focus Group

December 15, 1998

Purpose of December Workshop

- To develop views outlining the state of the Canadian hydrocarbon industry in 2050 and the types of technologies, including CO_2 capture and disposal, that could enable the industry to mitigate greenhouse gas emissions.

State of the Industry in 2050

- Canada continues to be a world producer of hydrocarbons
- Energy consumption patterns do not likely change dramatically
- Canadians continue to demand and use the existing "liquid fuels" infrastructure

Key Developments

- Canadian hydrocarbons could become more remote and more energy intensive
- Oil from conventional wells currently non-producible could become more viable given the growing use of CO_2 injection.
- Energy production and distribution systems could be collapsed and merged for greater efficiency
- Coal could continue to be major energy source

Coal

- Coal could have an important role, in particular:
  - CO_2 storage for the production of coal-bed methane
  - The gasification of coal to liquid fuels (including electrochemical separation)

Natural Gas

- Could remain an important source either in direct applications or through syngas
- Natural gas should have a premium, and its use match its higher value - do not use it as a bridging fuel
- Non-producing natural gas wells could be used for CO_2 storage

Carbon Sequestration

- Essential in the development of sustainable hydrocarbon sector
- Large potentials for sequestration in the oil patch, agriculture, forestry and ocean sectors.
- Key to sequestration is the need for:
  - better separation technologies
  - membranes for chemical feedstock applications.

Biotechnology

- Application of biotechnologies to produce designer liquid fuels
- Other biotechnology applications include:
  - anaerobic production of hydrogen for H_2S
  - bio-processing of oil sands and heavy oils may be possible.

Distributed Energy Systems

- Growing electrification of the economy will require:
  - varied sources of supply
  - reliance on superconductivity
  - energy storage systems (Electro-magnetic) to manage supplies on response to loads

Conclusions

- Such discussions regarding the future role of hydrocarbons in a sustainable energy system are essential.
- Hydrocarbons are an important component of the Canadian economy
  - We should not be embarrassed by our reliance on them, rather learn to use them smarter and cleaner - in a sustainable manner

ANNEX 8

Policy Issues arising from Assignment 1

Policy Issues – which impact on gas techs

- ✓ C tax
- ✓ No silver bullet
- ✓ Emissions trading
- ✓ Driving essentials of Cap & Trade
- ✓ Conflictin or augmenting policiies in Oother Countries
- ✓ Rolew or impact of Surprise or disruptive technologies - gas will not be affected in a mjajor way
- ✓ Fed/prov relations
- ✓ Is there an impending shortage of Natural Gas – switching technologies may be a mistake
- ✓ Investment on maintaing gas exploration techs & quality of production
- ✓ Who funds, sets goals for R&D
- ✓ Declining returns from WCSB
- ✓ Whole question of GHG targets
- ✓ Sequestration evaluation & measurement
- ✓ Technology assessement **must** be based on life cycle assessment

H/C contiues much as is
No silver bullet
Size of the pie – large % liquid & gaseous HC
Fully integrated gas industtry Gas in-ground + all other gaseous souerces
Some believe HG shortage

Summary of Coal

Cross-Cutting Tehnologies

H2 production techs	2000
Small gas fired electric generation	2005
Nano techs	2010
Expert systems	2015
Production automation	2020
Capacity to coordinate	2025
Micro wave techs for trasnsmission	
H2 storage	2020
Integrated energy management systems	2025

ANNEX 9

Revised Technology Step-Out Sheets

Technology Area	Electricity	Oil (Conventional/Non-Conventional Heavy Oil/Oil Sands)	Natural Gas	Coal	CO_2 Capture And Disposal
2000	• Deregulation sees short – term responses with natural gas and co-generation as main sources.				• CO_2 avoidance is the first step – improved efficiencies are far more economic
2005	• High efficiency gas turbines using advanced material for reduced CO_2 and NOX emissions.		• Deeper wells, smaller sour pools		• CO_2 for EOR • Commercial installations using CO_2 capture
2010	• Biomass co-fired with coal	• Renewed conventional oil industry – CO_2 injection	• Coal bed methane technically and economically feasible. • Natural gas decarbonisation - partial oxidisation		• CO_2 capture from hydrates from hydrates using gas separation technology • CO_2 based combustion systems
2015	• Fuel cell/gas turbine hybrids • Power plants using ceramic fuel cells and improved separation technologies	• SAGD Replacement - solvents	• Syngas from: coal, residues and gasification		• CO_2 disposal in aquifers with reversibility
2020	• Distributed Energy Systems	• Acid gas solvents for oil sands and heavy oils • Super fuels • Designer fuels using biotechnology • Hydrogen-diesel	• Coal bed methane operational		• Direct ocean disposal of CO_2 using various technologies
2025	• Industrial Energy Complexes emerge		• Arctic gas		
2030	• Wide spread energy storage • SEMS MW scale superconducting magnetic energy storage				• Iron seeding of oceans • Biotech designed plankton for oceans
2035	• End of stand alone power generation.		• Underground gasification of coal		• Membranes for CO_2 capture
2040	• Improved electricity distribution systems		• Gas hydrates as a source		
2045					• CO_2 neutral bitumen production
2050					

Technology Area	Electricity	Oil (Conventional/Non-Conventional Heavy Oil/Oil Sands)	Natural Gas	Coal	Co_2 Capture And Disposal
2025	• Industrial Energy Complexes emerge		• Arctic gas	• Coal [plexes incl liquifaction	
2030	• Wide spread energy storage • SEMS MW scale superconducting magnetic energy storage			• Coal gasification with CO2 extraction to 2050	• Iron seeding of oceans • Biotech designed plankton for oceans
2035	• End of stand alone power generation. To energy plexes			• Combined cycle plants with gasifiers • Underground gasification of coal	
2040	• Improved electricity distribution systems		• Gas hydrates as a source		
2045					• CO_2 neutral bitumen production
2050	• Naturally occuring hydrocarbons from all sources		• Fully integrated gas sources variety of sources • Deep well sour Arctic EC offshore • CBM , etc • Conventional • East Coast/west (?) Coast Offshore • Improved production of sour H2S, N, Co2 • Coal gasification • Control of fugative emissions • Gas hydrates (2020)	• Improved gasifiaction • Conversion of coal to other fuel forms • Naturally occuring hydrocarbons • MHD	• CO2 exreaction from air

Technology Area	Electricity	Oil (Conventional/Non-Conventional Heavy Oil/Oil Sands)	Natural Gas	Coal	Co_2 Capture And Disposal
2000	• Deregulation sees short – term responses with natural gas and co-generation as main sources.	• Venting & flaring • Improved technologies for leaks • Improved horizontal drillling tech • Co-gen at petroleum production treatment plant • Petroleum coke • Gasification techs	• NG storage	• Retrofit existing plants	• CO_2 avoidance is the first step – improved efficiencies are far more economic • CO_2 C&D essential • Sinks aforestation, reforestartion • Agric crops that consume CO_2 • CO_2 for EOR
2005	• High efficiency gas turbines using advanced material for reduced CO_2 and NOX emissions.	• Biotech for oil upgrading • Field upgrading (on site)	• Deeper wells, smaller sour pools (CO_2 N) • East Coast wells • Control of fugatives	• Long wall underground	• Commercial installations using CO_2 capture
2010	~~• Biomass co-fired with coal~~	• Renewed conventional oil industry – CO_2 injection • Down hole processing • Computerised energy well-head	• Coal bed methane & gas hydrate technology economically feasible. • Natural gas decarbonisation - partial oxidisation • Gas to liquids	• CO_2 extraction/ disposal from existing generation plants to 2025	• CO_2 capture hydrates using gas separation technology • CO_2 based combustion systems O2 enrichment technologies
2015	• Fuel cell/gas turbine hybrids • Power plants using ceramic fuel cells and improved separation technologies	• SAGD Replacement – n ow steam move to solvents • Re-enginnered processing systems • Improved solvent technoloy • Re-engineer the system integrtated 16 processes	• Syngas from: coal, residues and gasification	• IGCC	• CO_2 utilisation for petrochemicals • CO_2 disposal in aquifers with reversibility • Membranes for CO_2 capture
2020	• Distributed Energy Systems – wide spread	• Acid gas solvents for oil sands and heavy oils • Super fuels bioengineered fuels • Designer fuels using biotechnology • Hydrogen-diesel • Nuclear energy production cycle – produce steam and power at production sites • Closed loop systems	• Gas pipelines of 3x pressure • Coal bed methane operational production from gas hydrates	• Coal bed methane operational production from gas hydrates	• Direct ocean disposal of CO_2 using various technologies • CO2 sequestration into NG hydrates • CO2 – O2 recycling • Sequestration econom - overall system design implications

Technology Area	Electricity	Transportation	industry	Utilisation	CO_2 Capture And Disposal
2000	• Deregulation sees short – term responses with natural gas and co-generation as main sources.				• CO_2 avoidance is the first step – improved efficiencies are far more economic • CO_2 C&D essential • Sinks aforestation, reforestartion • Agric crops that consume CO2 • CO_2 for EOR
2005	• High efficiency gas turbines using advanced material for reduced CO_2 and NOX emissions.				• Commercial installations using CO_2 capture
2010	~~• Biomass co-fired with coal~~				• CO_2 capture hydrates using gas separation technology • CO_2 based combustion systems O2 enrichment technologies
2015	• Fuel cell/gas turbine hybrids • Power plants using ceramic fuel cells and improved separation technologies				• CO_2 utilisation for petrochemicals • CO_2 disposal in aquifers with reversibility • Membranes for CO_2 capture
2020	• Distributed Energy Systems – **wide spread**				• Direct ocean disposal of CO_2 using various technologies • CO_2 sequestration into NG hydrates • CO_2 – O2 recycling • Sequestration econom - overall system design implications
2025	• Industrial Energy Complexes emerge				
2030	• Wide spread energy storage • SEMS MW scale superconducting magnetic energy storage				• Iron seeding of oceans • Biotech designed plankton for oceans
2035	• End of stand alone power generation. **To energy plexes**				
2040	• Improved electricity distribution systems				
2045					• CO_2 neutral bitumen production
2050	• Naturally occuring hydrocarbons from all sources				• CO_2 exreaction from air

Technology Area	Oil (Conventional/Non-Conventional Heavy Oil/Oil Sands)	Natural Gas	Coal	CO_2 Capture And Disposal
2000	• Venting & flaring • Improved technologies for leaks • Improved horizontal drillling tech • Co-gen at petroleum production treatment plant • Petroleum coke • Gasification techs	• Deeper wells, smaller sour pools (CO2 N) • East Coast wells • Control of fugatives	• Retrofit existing plants	• CO_2 avoidance is the first step – improved efficiencies are far more economic • CO2 C&D essential • Sinks aforestation, reforestartion • Agric crops that consume CO2 • CO_2 for EOR
2005	• Biotech for oil upgrading • Field upgrading (on site)		• Long wall underground	• Commercial installations using CO_2 capture
2010	• Renewed conventional oil industry – CO_2 injection • Down hole processing • Computerised energy well-head	• NG storage • Coal bed methane & gas hydrate technology economically feasible. • Natural gas decarbonisation - partial oxidisation • Gas to liquids	• CO2 extraction/disposal from existing generation plants to 2025	• CO_2 capture hydrates using gas separation technology • CO_2 based combustion systems O2 enrichment technologies
2015	• SAGD Replacement – n ow steam move to solvents • Re-enginnered processing systems • Improved solvent technoloy • Re-engineer the system integrtated 16 processes	• Syngas from: coal, residues and gasification	• IGCC	• CO2 utilisation for petrochemicals • CO_2 disposal in aquifers with reversibility • Membranes for CO_2 capture
2020	• Acid gas solvents for oil sands and heavy oils • Super fuels bioengineered fuels • Designer fuels using biotechnology • Hydrogen-diesel • Nuclear energy production cycle – produce steam and power at production sites • Closed loop systems	• Coal bed methane production and gas hydrates operational and production	• Coal bed methane operational production from gas hydrates	• Direct ocean disposal of CO_2 using various technologies • CO2 sequestration into NG hydrates • CO2 – O2 recycling • Sequestration econom - overall system design implications

Technology Area	Oil (Conventional/Non-Conventional Heavy Oil/Oil Sands)	Natural Gas	Coal	CO_2 Capture And Disposal
2025		• Arctic gas	• Coal [plexes incl liquifaction	
2030			• Coal gasification with CO2 extraction to 2050	• Iron seeding of oceans • Biotech designed plankton for oceans
2035			• Combined cycle plants with gasifiers • Underground gasification of coal	
2040				
2045				• CO_2 neutral bitumen production
2050		• Fully integrated gas sources variety of sources - Deep well sour Arctic EC offshore - CBM , etc - Sources of today & new ones - Conventional - East Coast/west (?) Coast Offshore - Improved production of sour H2S,N, Co2 - Coal gasification - Control of fugative emissions - Gas hydrates (2020)	• Improved gasifiaction • Conversion of coal to other fuel forms • Naturally occuring hydrocarbons • MHD	• CO2 exreaction from air